⑫ **EUROPEAN PATENT APPLICATION**
published in accordance with Art.
158(3) EPC

㊼ **SERVO MOTOR CONTROLLER.**

㊽ A servo motor controller for effecting a model reference speed control. An acceleration signal is derived from a speed signal fed back from a servo motor based on differential or difference calculus, an acceleration value of the servo motor (d) is estimated relying on a reference model (2) of the speed control system utilizing a current instruction (T(s)) formed in the speed control loop, the calculated acceleration is compared with an estimated acceleration, and the current instruction (T(s)) is corrected depending upon the result of comparison.

Fig. 1

SERVOMOTOR CONTROL APPARATUS

Technical Field

This invention relates to a servomotor control apparatus having improved characteristics, such as a frequency response characteristic.

Background Art

In servomotor velocity control, ordinarily it is so arranged that a velocity signal fed back from the servomotor is compared with a velocity command. Fig. 4 is a block diagram showing an example of such a conventional control system in a case where disturbances are neglected. In Fig. 4, a represents an integration term having an integration gain K_1, b a proportion term having a proportional gain K_2, c a current amplification term of torque constant K_T, and d a motor term which includes motor rotor inertia J_M and a constant β indicating load inertia. Further, s represents an integration operator.

With this velocity control system, the sum of the result of integrating an error signal between a velocity command V(s) and motor velocity W(s) by K_1/S of the integration term and the result of feeding back the motor velocity W(s) through the proportional gain K_2 of the proportion term b is applied to the motor d as a torque command T(s) (current command).

In such a velocity control system, a time delay develops in the response of the torque command T(s) owing to the integration term a, and instability occurs such as control system oscillation when the system gain is enlarged. More specifically, the system cannot quickly follow up rapid changes in the commanded velocity V(s), and oscillation is produced particularly when the motor is controlled to be brought to a stop.

Disclosure of the Invention

The present invention has been devised in order to solve the foregoing problems and its object is to provide a servomotor control apparatus in which frequency response is raised and velocity can be controlled stably by mitigating the effects of disturbances and fluctuations in load.

In accordance with the invention, there can be provided a servomotor control apparatus having a velocity control loop which includes a control criterion model for performing standard model-type control with regard to a servomotor, comprising means for forming an acceleration signal by dif-

ferentiating a velocity signal fed back from the motor, means for estimating an acceleration value of the servomotor using a current command outputted by the velocity control loop, means for obtaining an error between the acceleration signal and the estimated acceleration value, and means for correcting the current command by the error signal.

Accordingly, the servomotor control apparatus of the present invention compares a computed acceleration and the estimated acceleration and enables the current command to be corrected in conformity with the results of the comparison to make possible stabilized velocity control.

Brief Description of the Drawings

Fig. 1 is a block diagram illustrating an embodiment of the invention having a standard model-type velocity control loop,

Fig. 2 is a block diagram of velocity control system which takes the effects of disturbances into account,

Fig. 3 is a block diagram for describing parallel-type model standard control, and

Fig. 4 is a block diagram illustrating an example of a conventional velocity control loop.

Best Mode for Carrying Out the Invention

An embodiment of the present invention will now be described in detail with reference to the drawings.

Since model standard-type adaptive control is used in the present invention, the principle of control will be described first.

Fig. 3 is a block diagram illustrating an example of parallel-type model standard control. As shown in Fig. 3, a criterion model 2 is arranged in parallel with a controlled system 1, an adjustable gain 3 provided ahead of the controlled system 1 is corrected adaptively during operation of the controlled system 1, and gain control is performed by an adaptive controller 4 in conformity with the output of an arithmetic unit 5 in such a manner that an output $\hat{I}_{OUT}$ of the controlled system 1 will follow up an output $\hat{I}_{OUT}$ of the criterion model 2. $\hat{I}_{REF}$ represents a command signal, and e denotes an error signal. Such model standard-type adaptive control is advantageous in that adaptive control of the control system can be performed with a quick response.

Fig. 1 is a block diagram illustrating an em-

bodiment of the present invention. Portions identical with those of Figs. 3 and 4 are designated by like reference characters and a description thereof is deleted. This embodiment of the invention having a model standard-type velocity control loop is characterized in that a coefficient α of the criterion model 2 of the velocity control system is set to a value at which the cut-off frequency and damping coefficient of the velocity control loop will be made equal to what they are when a corrective gain coefficient $K_A = 0$ holds, and in that corrective gain K_A is provided as the adjustable gain 3. That is, along with the velocity feedback loop, an acceleration feedback loop is formed by providing an arithmetic unit 6 having the differentiation operator s to differentiate the motor velocity $W(s)$, acceleration is estimated by the criterion model 2 based on the current command $T(s)$, and the acceleration is compared with the fed back acceleration signal by the arithmetic unit 5 to correct the current command $T(s)$.

Described next will be a transfer function $H(s)$ = $W(s)/V(s)$ in the control loop of Fig. 1.

In Fig. 1, the relationship among a velocity command Vcmd [= $V(s)$], torque command $T(s)$, corrective torque signal $A(s)$ and motor velocity $W(s)$ is as follows:

$T(s) = (K_1/S)V(s) - \{(K_1/S) + K_2\}W(s)$
$A(s) = K_A\{(\alpha K_T/J_M)T(s) - SW(s)\}$
$W(s) = [K_T/\{SJ_M(1 + \beta)\}]\{T(s) + A(s)\}$

The transfer function $H(s)$ is as follows:

$H(s) = K_TK_1 \{1 + \alpha K_AK_T/J_M\}/[\{J_M(1 + \beta) + K_TK_A\}S^2 + K_TK_2 \{1 + (\alpha K_AK_T/J_M)\}S + K_TK_1 \{1 + (\alpha K_AK_T/J_M)\}]$ (1)

(A) Regarding the transfer function $H_0(s)$ when the corrective gain $K_A = 0$

This corresponds to the conventional example shown in Fig. 4, namely an arrangement in which there is no acceleration feedback system. Assuming that the transfer function $H_0(s) = W(s)/V(s)$, we have

$H0(s) = (K_TK_1)/\{J_M(1 + \beta)S^2 + K_TK_2S + K_TK_1\}$ (2)

Here the integration term a and proportion term b are adjusted in conformity with the load inertia ratio, so that we have

$K_1 = (1 + \beta_0)K_{10}$, $K_2 = (1 + \beta_0)K_{20}$

where β_0: constant corresponding to the load inertia ratio

If the constant β indicating the load inertia is as follows:

$\beta = \beta_0$

Eq. (2) can be expressed as follows:

$H0(s) = K_TK_{10}/(1 + \beta_0)/\{J_M(1 + \beta_0)S^2 + K_T(1 + \beta_0)K_{20}S + K_TK_{10}(1 + \beta_0)\}$

$= \omega n^2/(S^2 + 2\zeta\omega nS + \omega n^2)$ (3)

where $(K_TK_{10})/J_M = \omega n^2$, $(K_T/J_M)K_{20} = 2\zeta\omega n$.

(B) Regarding the transfer function $H(s)$ when the corrective gain $K_A \neq 0$ and the coefficient $\alpha = 0$

Here system operation will be described when the conventional velocity feedback system is provided solely with the acceleration feedback function shown in Fig. 1. Assuming that the transfer function is $H(s) = W(s)/V(s)$, we have

$H(s) = (K_TK_1)/[\{J_M(1 + \beta) + K_TK_A\}S^2 + K_TK_2S + K_TK_1]$ (4)

This indicates that, in comparison with Eq. (2), provision solely of acceleration feedback is equivalent to effecting a pseudo-increase in motor rotor inertia.

(C) Regarding the transfer function $H(s)$ when the corrective gain $K_A \neq 0$ and the coefficient $\alpha \neq 0$

This corresponds to a case where model standard control shown in Fig. 1 is provided with acceleration feedback. By making the criterion mode coefficient α equal to $1/(1 + \beta)$, the behavior exhibited is the same as that in the conventional velocity control system with respect to the velocity command, and the apparent motor rotor inertia is enlarged so that the system presents improved stability. That is, the transfer function $H(s)$ becomes as follows, where the substitution $(\alpha K_T/J_M) = \alpha'$ is made in Eq. (1):

$H(s) = K_TK_1\{1 + \alpha'K_A\}/[\{J_M(1 + \beta) + K_TK_A\}S^2 + \{K_TK_{20}(1 + \beta_0)(1 + K_A\alpha')S\} + \{K_TK_{10}(1 + \beta_0)(1 + \alpha'K_A)\}]$

Next, when K_A is decided in such a manner that $K_TK_A/J_M(1 + \beta) = P$ holds, namely when the apparent rotor inertia becomes $(1 + P)$ times larger, α becomes as follows from $K_a\alpha' = P$

$\alpha = 1/(1 + \beta)$

Accordingly, the transfer function $H(s)$ is

$H(s) = K_TK_{10}(1 + \beta_0)(1 + P)/[J_M(1 + \beta)(1 + P)S^2 + K_TK_{20}(1 + \beta_0)(1 + P)S + K_TK_{10}(1 + \beta_0)(1 + P)]$

$= \{K_TK_{10}(1 + \beta_0)\}/[J_M(1 + \beta)S^2 + K_TK_{20}(1 + \beta_0)S + K_TK_{10}(1 + \beta_0)]$ (5)

More specifically, by setting α to be equal to $1/(1 + \beta)$, Eq. (5) is such that the velocity loop exhibits the same behavior as when $K_A = 0$ (the prior-art example) with respect to the velocity command $V(s)$, and the apparent motor rotor inertia becomes larger at the same time so that the velocity loop exhibits improved velocity control system stability.

Fig. 2 is a block diagram of a velocity control system that takes the influence of disturbance into

account. Before investigating the effects of distur-
bance, the influence of a change in inertia on the
transfer function will be considered.

(a) Influence of a fluctuation in load inertia

Described first will be the influence of a fluc-
tuation in inertia on the transfer function $H(s)$ when
the motor inertia coefficient β is represented by β-
(s). The transfer coefficient $H(s)$ may be written as
follows from Eq. (1):

$H(s) = K_T K_{10}(1 + \alpha' K_A)(1 + \beta_0)/(J_M(1 + \beta(s)) + K_T K_A)S^2 + K_T K_{20}(1 + \beta_0)(1 + K_A\alpha')S + K_T K_{10}(1 + \beta_0)(1 + \alpha' K_A)]$

The influence of the fluctuation in inertia on the
transfer function $H(s)$ is evaluated by the following
equation:

$\{\partial H(s)/\partial \beta(s)\}$
$= \{-K_T K_{10}(1 + \alpha' K_A)J_M S^2(1 + \beta_0)/[\{J_M(1 + \beta(s)) + K_T K_A\}S^2 + K_T K_{20}(1 + \beta_0)(1 + K_A\alpha')S + K_T K_{10}(1 + \beta_0)(1 + \alpha' K_A)]^2$ (6)

If $K_A = 0$ holds, we have the following from Eq.
(2):

$\{\partial H_0(s)/\partial \beta(s)\}$
$= \{-K_T K_{10}(1 + \beta_0)J_M S^2/\{J_M(1 + \beta(s))\}S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}^2$ (7)

Next, the following is obtained from Eqs. (6),
(7):

$G_i(s) = \{\partial H(s)/\partial \beta(s)\}/\{\partial H_0(s)/\partial \beta(s)\}$ (8)

If the coefficient α of the criterion model is
made equal to $1/(1 + \beta_1)$, as mentioned earlier,
then we will have the following since $K_A = P(1 + \beta_1) \times (J_M/K_T)$

$K_A\alpha' = K_A \times (K_T/J_M)\alpha$
$= P(1 + \beta_1)(J_M/K_T)(K_T/J_M)\{1/(1 + \beta_1)\}$
$= P$

Though $\beta(s)$ fluctuates in the vicinity of 1, we arrive
at the following if the range of fluctuation is ne-
glected and $1 + \beta(s) \backsimeq 1 + \beta_1$ is assumed to
hold:

$G_i(s)$
$= \{J_M(1 + \beta_1)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}^2 \times (1 + P)/(1 + P)^2\{J_M(1 + \beta_1)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10})(1 + \beta_0)\}^2$

$= 1/(1 + P)$ (9)

Eq. (9) indicates that when the corrective gain K_A is
determined in such a manner that the motor rotor
inertia becomes $(1+P)$ times larger and is deter-
mined in such a manner tht the cut-off frequency
and damping coefficient of the velocity control sys-
tem become equal to what they will be at $K_A = 0$,
the influence of the change in load interia upon the
change in the velocity loop transfer function can be
reduced to a value which is $1/(1 + P)$ times as
much.

(b) Influence of disturbance

The influence of a variation in torque upon
output velocity will now be considered on the basis
of a transfer function for a case where a torque
disturbance $T_D(s)$ is taken into account in Fig. 2.

If it is assumed that a torque command $T(s) = (K_1/S)V(s) - \{(K_1/S) + K_2\}W(s)$, a torque command
signal $A(s) = K_A\{(\alpha K_T/J_M)T(s) - SW(s)\}$ and a mo-
tor velocity $W(s) = [1/\{SJ_M(1 + \beta)\}][T_D(s) + K_T\{T(s) + A(s)\}]$, then the following equation will
hold with regard to motor velocity $W(s)$:

$W(s) = [1/\{SJ_M(1 + \beta)\}] \times [T_D(s) + K_T\{T(s) + K_A\{(\alpha K_T/J_M)T(s) - SW(s)\}]]$ (10)

Solving Eq. (10) with regard to motor velocity
$W(s)$, we have

$W(s) = [K_T K_{10}(1 + \beta_0)(1 + K_A\alpha')V(s) + ST_D(s)]/[\{J_M(1 + \beta) + K_A K_T\}S^2 + K_T K_{20}(1 + \beta_0)(1 + K_A\alpha')S + K_T K_{10}(1 + \beta_0)(1 + K_A\alpha')]$ (11)

The manner in which the motor velocity $W(s)$ varies
due to a change in torque disturbance $T_D(s)$ will
now be investigated based on the foregoing. Spe-
cifically, we have

$\{\partial W(s)/\partial T_D(s)\}$
$= S/[J_M(1 + \beta) + K_A K_T]S^2 + K_T K_{20}(1 + \beta_0)(1 + K_A\alpha')S + K_T K_{10}(1 + \beta_0)(1 + K_A\alpha')]$ (12)

Letting $W_0(s)$ represent motor velocity when $K_A = 0$ prevails, we have

$W_0(s)$
$= \{K_T K_{10}(1 + \beta_0)V(s) + ST_D(s)\}/\{J_M(1 + \beta)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}$ (13)

Therefore,

$\{\partial W_0(s)/\partial T_D(s)\}$
$= T_D(s)/\{J_M(1 + \beta)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}$ (14)

Accordingly, we have the following from Eqs. (12),
(14):

$G_{TD}(s)$
$= \{\partial W(s)/\partial T_D(s)\}/\{\partial W_0(s)/\partial T_D(s)\}$
$= \{J_M(1 + \beta)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}/[\{J_M(1 + \beta) + K_A K_T\}S^2 + K_T K_{20}(1 + \beta_0)(1 + K_A\alpha')S + K_T K_{10}(1 + \beta_0)(1 + K_A\alpha')]$ (15)

Accordingly, if the coefficient α of the criterion
model is made equal to $1/(1 + \beta)$ and $K_A = P(1 + \beta)(J_M/K_T)$ holds, then we have

$G_{TD}(s)$
$= \{J_M(1 + \beta)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}/(1 + P)\{J_M(1 + \beta)S^2 + K_T K_{20}(1 + \beta_0)S + K_T K_{10}(1 + \beta_0)\}$
$= 1/(1 + P)$ (16)

Eq. (9) indicates that when the corrective gain K_A is
determined in such a manner that the motor rotor
inertia becomes $(1+P)$ times larger and α is deter-
mined in such a manner that the cut-off frequency
and damping coefficient of the velocity control sys-
tem become equal to what they are when $K_A = 0$
holds, the influence of the change in load interia
upon the change in the velocity loop transfer func-

tion can be reduced to a value which is 1/(1 + P) times as much.

Though an embodiment of the invention has been described, the invention is not limited thereto but can be modified in various ways without departing from the scope of the claims.

Industrial Applicability

The servomotor control apparatus of the present invention is such that the velocity control system of a servomotor is provided with a loop which forms an acceleration signal by differentiating motor velocity, acceleration serving as a model criterion is specified using a current comand, this estimated value and an acceleration signal are compared and the current command is corrected. As a result, frequency response is improved and the influence of disturbance and torque variation can be diminished to make stable control possible.

Claims

1. A servomotor control apparatus having a velocity control loop which includes a control criterion model for performing standard model-type control with regard to a servomotor, comprising:
means for forming an acceleration signal by differentiating a velocity signal fed back from said motor;
means for estimating an acceleration value of the servomotor using a current command outputted by said velocity control loop;
means for obtaining an error between said acceleration signal and the estimated acceleration value; and
means for correcting said current command by said error signal.

2. A servomotor control apparatus according to claim 1, characterized in that a corrective gain is provided with respect to the error between said acceleration signal and the estimate acceleration value, an error signal being obtained by setting a corrective gain coefficient K_A in conformity with a fluctuation in load inertia.

3. A servomotor control apparatus according to claim 2, characterized in that the means for estimating the acceleration value of said servomotor is such that the control criterion model is $\alpha(K_T/J_M)$ (where K_T represents a torque constant and J_M represents motor rotor inertia), the coefficient α being set to a value at which a cut-off frequency and damping coefficient of the velocity control loop will be made equal to what they are when the corrective gain coefficient $K_A = 0$ holds.
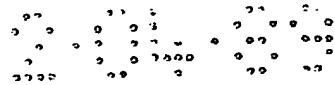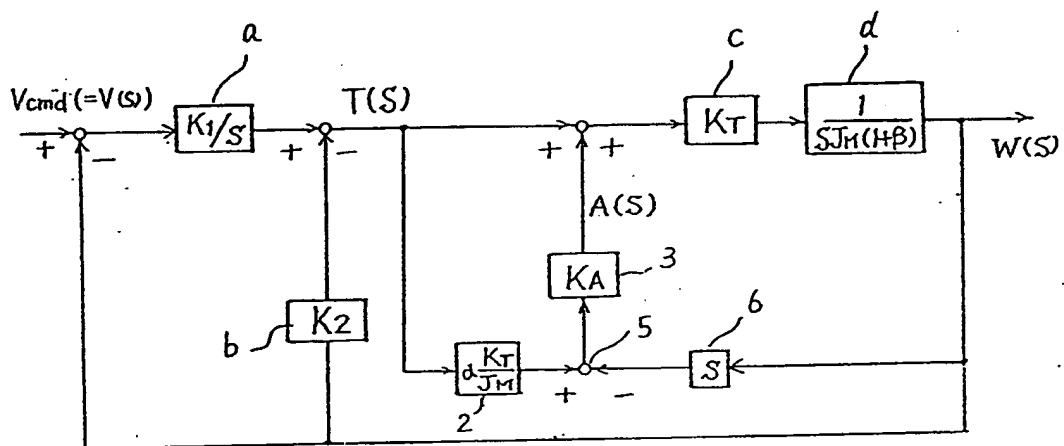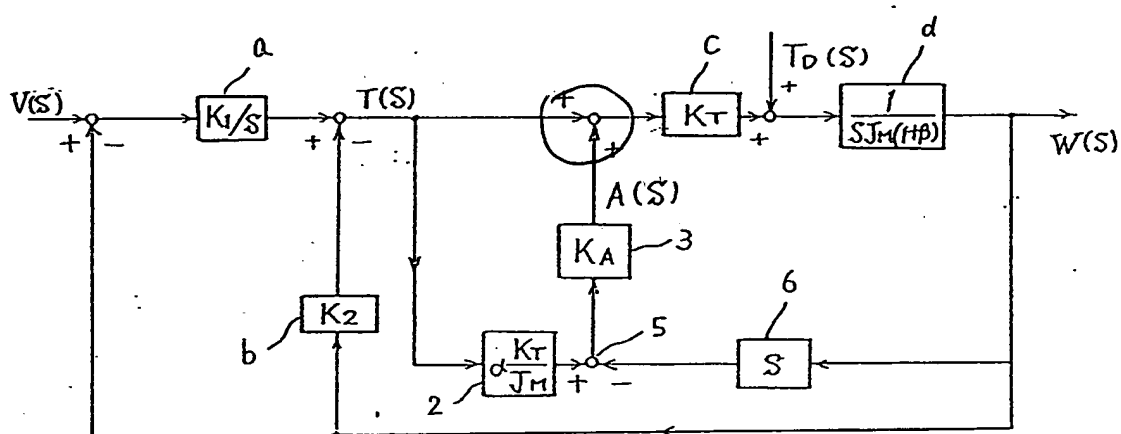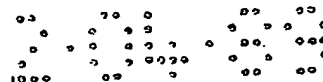
Fig. 1

Fig. 2

Fig. 3
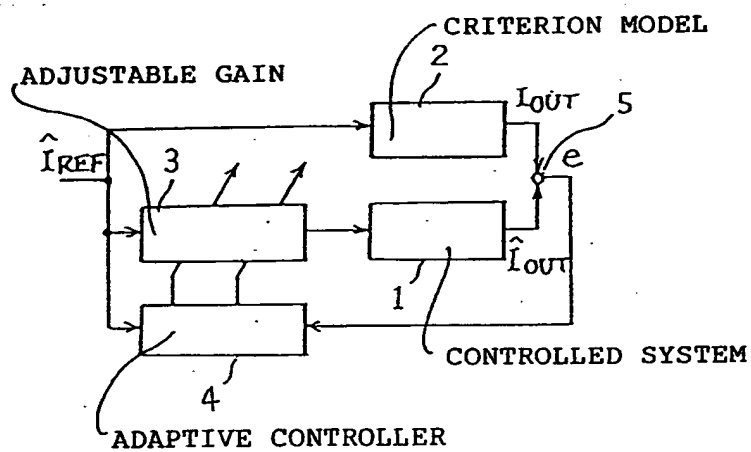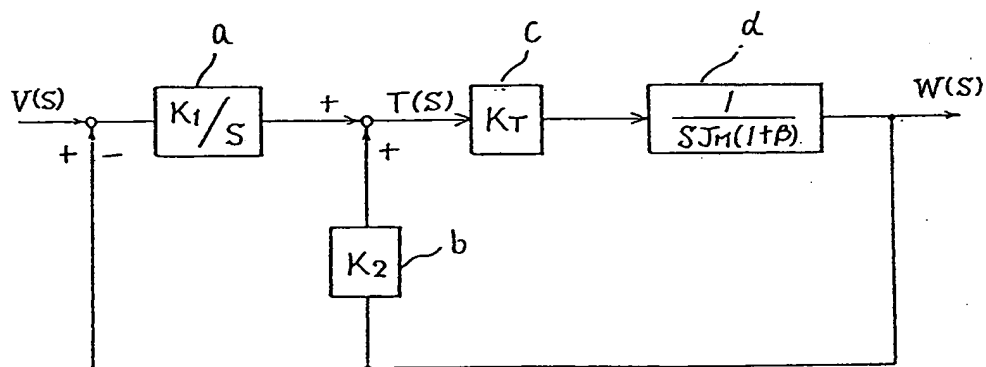
CRITERION MODEL

ADJUSTABLE GAIN

$\hat{I}_{REF}$

I_{OUT}

$\hat{I}_{OUT}$

CONTROLLED SYSTEM

ADAPTIVE CONTROLLER

Fig. 4

$V(S)$ + − K_1/S + $T(S)$ K_T $\dfrac{1}{SJ_M(1+\beta)}$ $W(S)$

K_2

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl⁴ $H02P5/00$

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷	
Classification System	Classification Symbols
IPC	$H02P5/00, G05D3/12$

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁸

Jitsuyo Shinan Koho	1960 – 1987
Kokai Jitsuyo Shinan Koho	1971 – 1987

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	JP, A, 57-199487 (Fuji Electric Co., Ltd.) 7 December 1982 (07. 12. 82) (Family: none)	1-3
Y	JP, A, 60-17510 (Sumitomo Electric Industries, Ltd.) 29 January 1985 (29. 01. 85) (Family: none)	1-3

* Special categories of cited documents: ¹⁰

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
December 5, 1988 (05. 12. 88)	December 19, 1988 (19. 12. 88)
International Searching Authority	Signature of Authorized Officer
Japanese Patent Office	